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14. ABSTRACT

The Combat Rations Network (CORANET) is a Defense Logistic Agency (DLA) sponsored manufacturing technology program to improve the quality, reduce the cost, and increase the productivity of operational rations while increasing DLA's surge capability in the area of military rations. This report summarizes results obtained in Phase I of contract STP 2005. Objective of the proposal in phase I was to determine the feasibility of using RF technology to produce shelf-stable egg products, with an optimum taste and texture, in a pilot plant setting. The use of an automatic program to control RF heating was initiated during an Interim Progress Review at WSU. We developed the program based on the heating pattern of five manual runs of RF heating. Temperature and over pressure of circulating water was controlled automatically over time. The repeatability of RF heating based on the automatic program was determined. We produced 10 trays of RF heated scrambled eggs without any temperature tubings in the tray. Incubation studies of 6 trays at 37 °C were conducted. There was no gas production observed after incubation for 10 days. Heat distribution inside an RF

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FINAL REPORT FOR PROJECT STP 2005 PHASE I

Thermal Stabilizing of Shelf-Stable Egg Products Based on Radio Frequency Energy Technology

by
Radio Frequency Team
Contact: Juming Tang, Ph.D.
Department of Biological Systems Engineering
Washington State University
April 1, 2005

This report summarizes results obtained in Phase I of contract STP 2005. Objective of the proposal in phase I is to determine feasibility of using RF technology to produce shelf-stable egg products, with an optimum taste and texture, in a pilot plant setting. Results from each specific task listed in the proposal to achieve the objective are summarized as follows:

Task 1. Kick–Off Meeting

The principal investigator Dr. Juming Tang and Dr. Gustavo Barbosa-Canovas participated in the Egg Umbrella Kick-off Meeting in February, 2003 at Natick Soldier Center and met with project participants/sponsors.

Task 2. Improvement of RF Unit

1. Manufacturing of a new high-pressure proof RF vessel
Improvement to the previous RF vessel was necessary to avoid arching and unstable heating and to reduce loading and unloading time. The criteria for the improved vessel design are listed as follows:

1. Electrical field:
    - A uniform electric field to the product being processed.
    - No direct electrical path between the plates.
    - No arching between two electrodes.
    - Constructed of materials that are not subject to dielectric heating.

2. High temperature, high pressure:
    - Use materials that endure sterilization temperatures up to 131°C (268 °F).
    - Withstand an overpressure sufficient to suppress boiling at sterilization temperatures up to 131°C (>abs. 40.5 psi).

3. Others considerations:

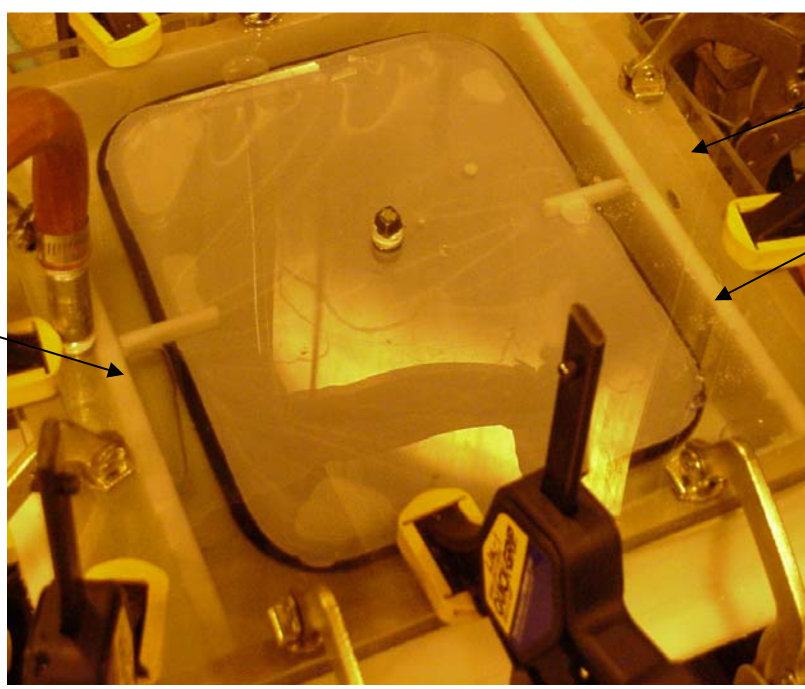
- Allow circulation of water during heating. Normally, the range of flow rate is from 6.1 liter/min to 11 liter/min during processing.
- Compatible with the existing RF applicators (plate).
- Accommodate a 6-pound capacity tray ration (292 × 229 × 49 mm, with a wall of 1.6 mm thick) or a retort pouch of similar size.
- Easy to load and unload the food package (tray and pouch etc).

Prior to the improvement, we built a mock-up unit using transparent plastic sheets to study the pattern of immersion water flow and air pockets development in the vessel. We then had the WSU Technical Service Center manufacture a new high-pressure proof vessel to improve heating uniformity and reduce chance of arching. During the manufacturing process, we worked very closely with staff members of the Technical Service Center, exchanged opinions and ideas on a daily bases. We conducted test runs to investigate different aspects of the design and develop solutions to problems as they occurred.

The two major differences between the new vessel and the old vessel are: 1) added front vessel door to provide an easy means for loading and unloading the food package, as compared to the opening of top plate in the old vessel; 2) added perforated distribution board to allow uniform horizontal water flow, as compared to vertical flow of the previous design to prevent development of air pockets that influence process stability.

The new vessel was tested to heat several food products such as mashed potatoes and scrambled eggs. Relatively uniform heating pattern was obtained. There was no arching with the new pressurized vessel over the course of one year tests – the new design concept appears to work well.

Figure 1. A mock-up unit built from plastic sheets to study the flow of immersion water and development of air pocket in the vessel.



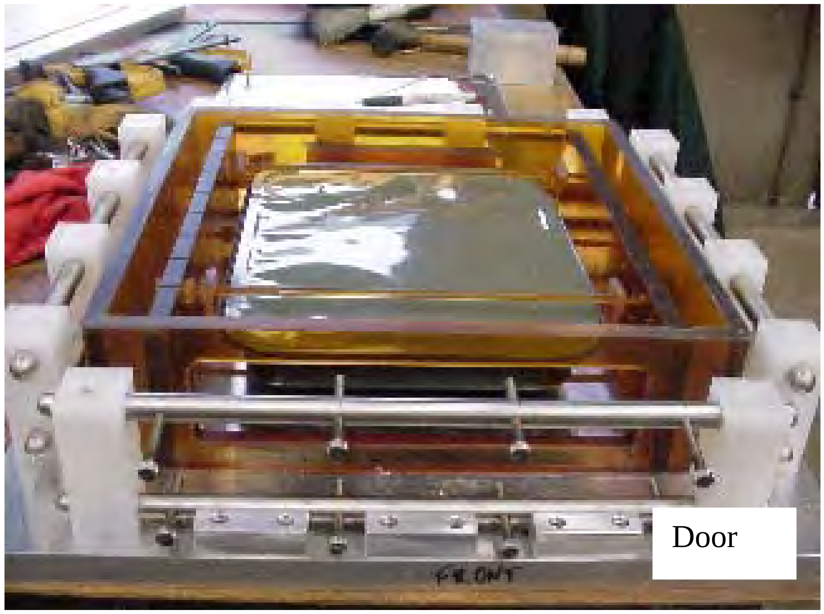


Figure 2. Front view of the vessel with a 6-lb polymeric tray

2. Develop a new RF sterilization system with a pressurized vessel for 4 trays, with pressure >25 psi

For the next generation of RF sterilization system, a semi-industrial sterilization chamber capable of processing four group-size polymeric trays at a time was designed. This task was divided into five main parts: a) developing simulation model to guide the design of the new system to ensure optimized energy coupling and heating uniformity; b) modify a 25 kW RF power supply unit (costing about $120,000, donated by Strayfield Ltd, UK) to allow effective delivery of RF energy to a pressurized vessel; c) design and manufacturing of a pressurize vessel with appropriate mechanisms for moving trays, inserting temperature probes, loading and unloading trays; d) develop and build a pressurized water heating, cooling and circulating system; e) system assembly, testing, and instrumentation. Our experiences gained in the experimentation of egg products with the improved pressurized vessel provided insights for the design of the new generation RF system. The RF egg team members participated in regular meetings of a separate RF design team. For more information for the progress of the design, refer to ANNUAL PROGRESS REPORT FOR PROJECT DAAD16-03-C-0056, Optimization of RF Sterilization for Military Group Rations.

Task 3. Product and process development

a. Determination of dielectric properties

The dielectric properties of foods determine the coupling and distribution of energy from an electromagnetic field to foods during RF heating. Since dielectric properties are temperature dependent, the dielectric properties of the material must be known over the full range of temperatures experienced by the product to allow prediction of its heating behavior. A dielectric properties measurement system (Figure 3) designed and developed at WSU was used to determine the dielectric properties of liquid/solid whole egg, and liquid/solid egg white.

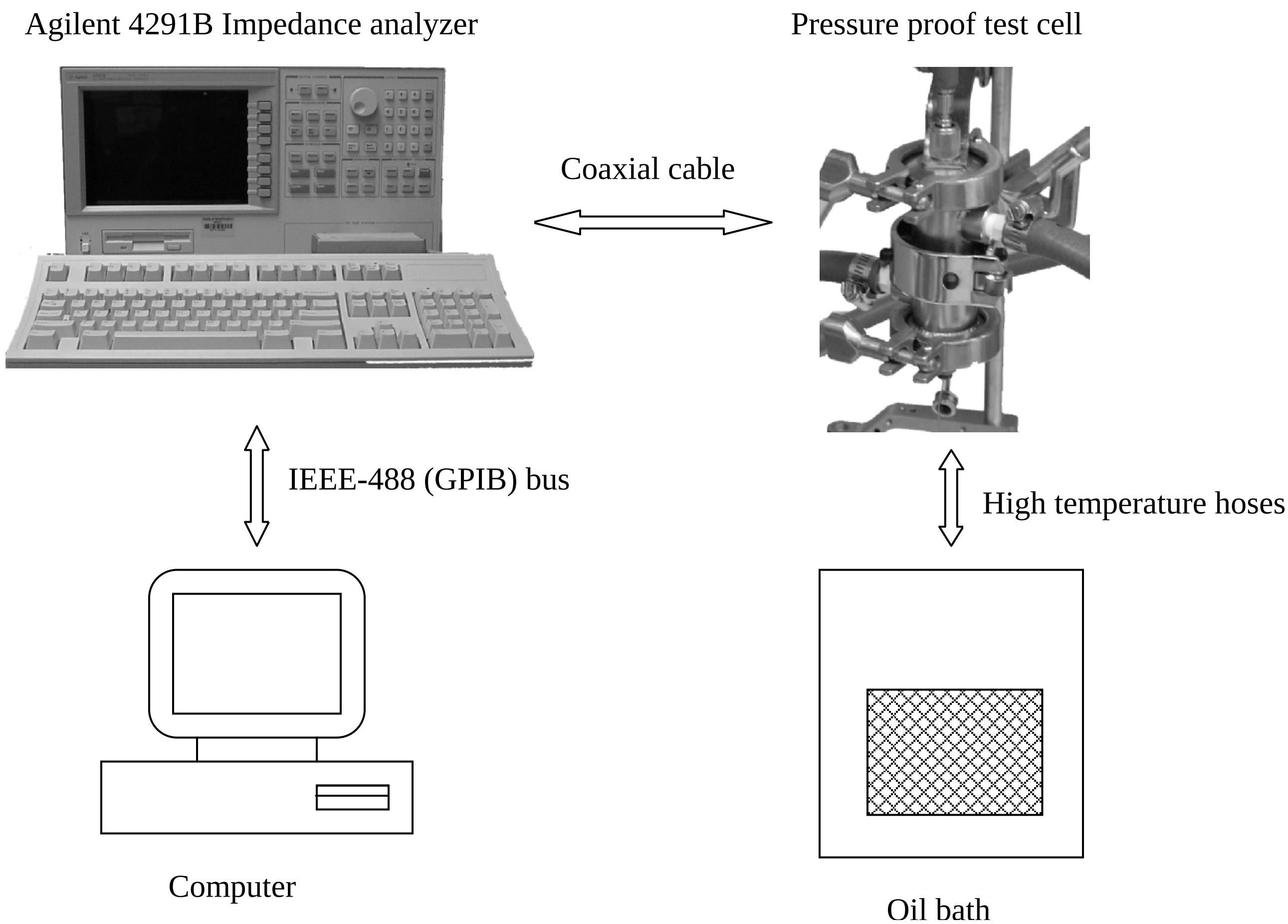


Figure3. Dielectric properties measurement system

Measurements of liquid and solid whole egg were conducted at every 10 °C increment from 20 to 121.1 °C. Ten minutes were allowed to achieve each 10 °C increment in the sample before dielectric properties were measured. This period was adequate for the sample to reach a stable temperature. We loaded about 15 g liquid egg into the test cell. To prepare solid whole egg, we put about 100 g liquid egg in a beaker, then used an 80 °C water bath to cure the egg. After the egg was cured, we loaded about 15 g solid egg into the test cell.

The preparation of liquid and solid egg white was the same as that of whole egg. The temperature range of measurement was the same as that of whole egg. The results were presented from Figure 4 to Figure 7.

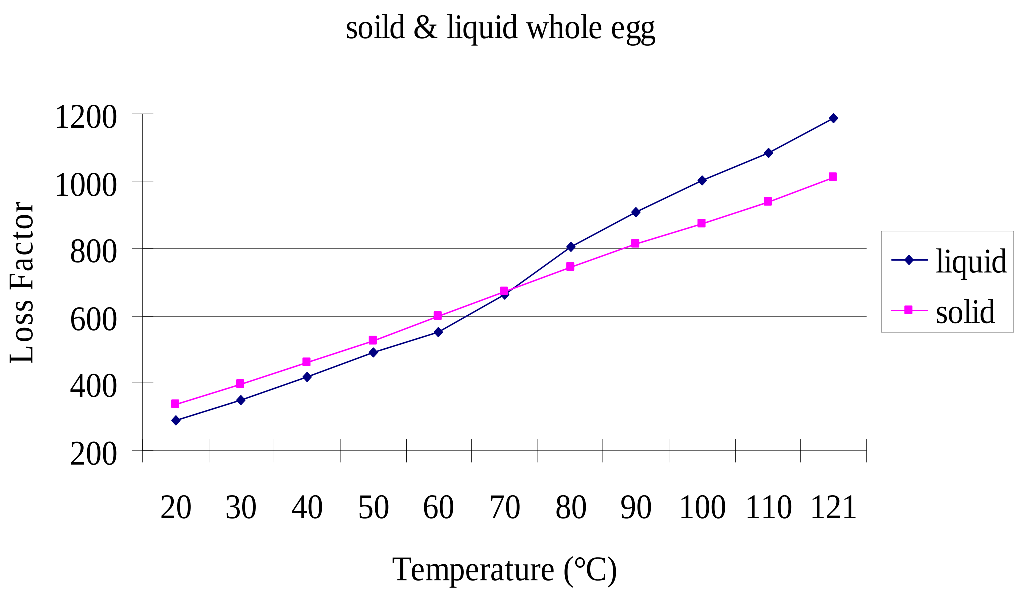


Figure 4. Loss factors of solid and liquid whole egg.

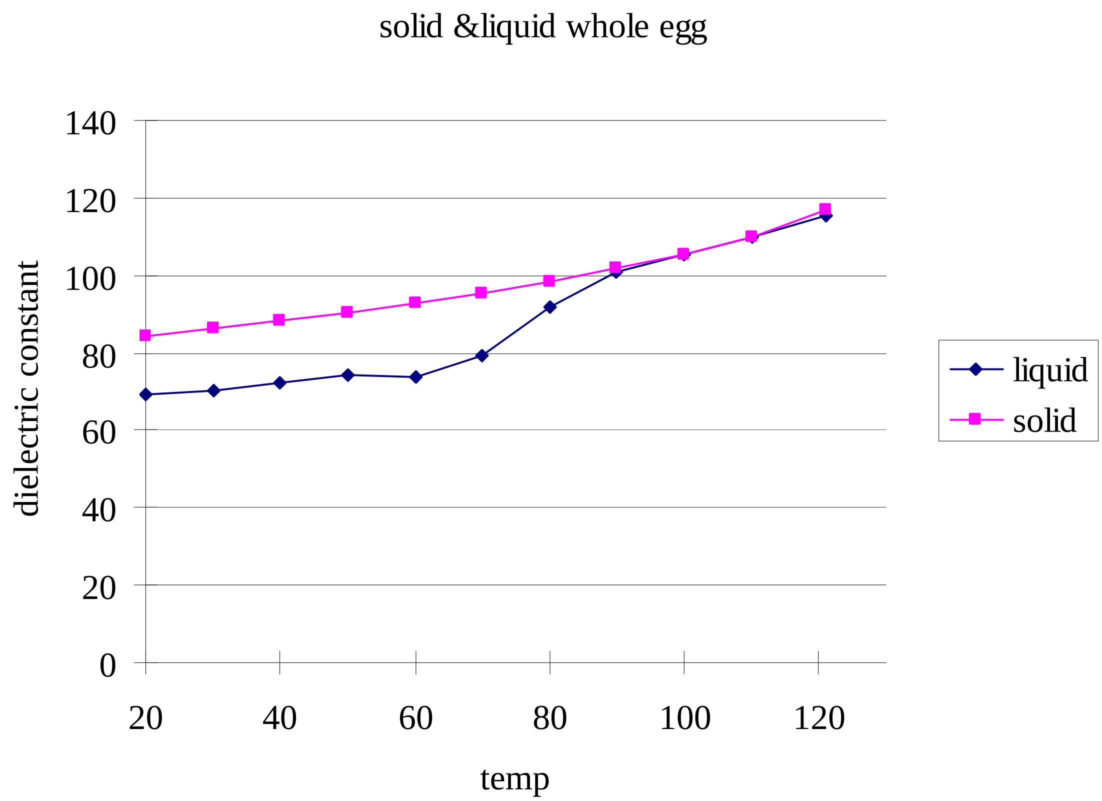


Figure 5. Dielectric constants of solid and liquid whole egg

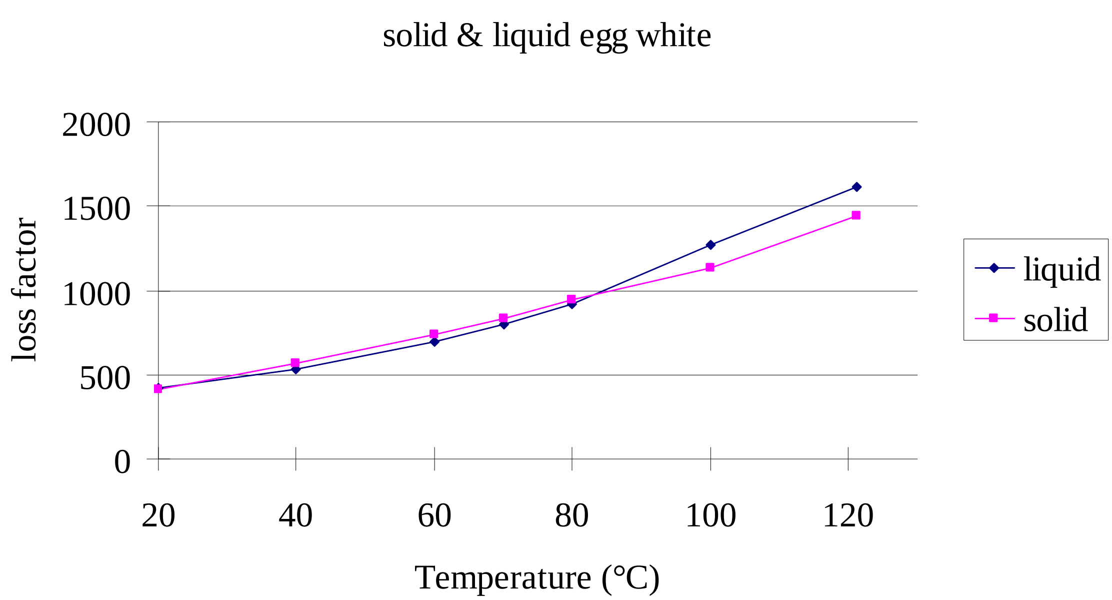


Figure 6. Loss factors of solid and liquid egg white

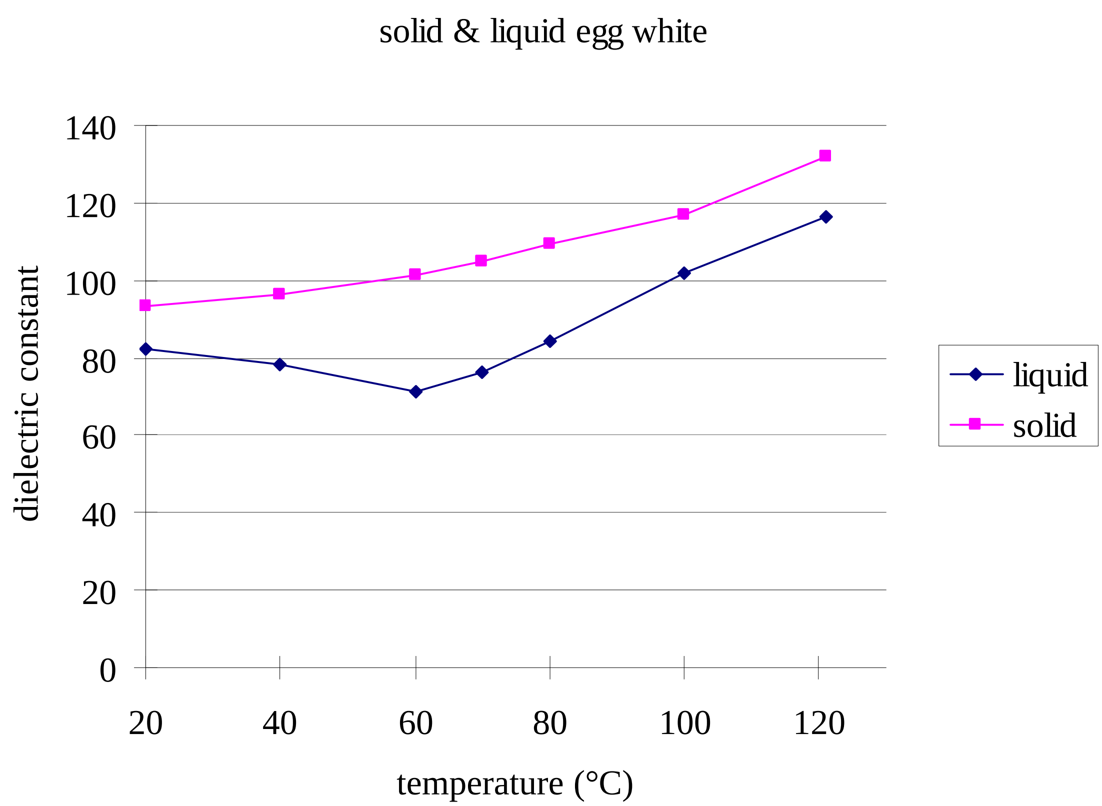


Figure 7. Dielectric constant of solid and liquid egg white

In summary, the loss factors of liquid and solid whole egg increased from about 300 to 1,200 as temperature increased from 20 °C to 121 °C. This suggests that we need to provide a very uniform electric field for RF heating of eggs to prevent possible thermal run away.

The above results will serve as baseline for us to evaluate effect of different ingredients on the dielectric properties of formulated egg products.

b. Selection of egg formulation and RF testing
Preliminary results of RF heated scrambled eggs showed greenish-black discoloration and an undesirable syneresis after processing and storage. In order to select a suitable formulation for RF heating, effects of ingredients, packaging, and cooking methods on scrambled egg quality were studied

The amount of citric acid greater than 0.17% resulted in an undesirable sour taste. Therefore, the maximum amount of citric acid should not be greater than 0.17%. Our results indicate that pH of the eggs controlled in the range of 6.8 to 7.1 would prevent discoloration. Scrambled eggs in this study were prepared from pasteurized whole eggs which came with 0.15% citric acid from the manufacturer (Michael Foods Egg Products

Co., MN). Therefore, only a small amount of additional citric acid was needed to prevent discoloration. Our test results indicate that citric acid of 0.15% was necessary to prevent greenish-black discoloration.

Our experiments also suggest that discoloration was not only caused by the amount of citric acid, but also by the amount of syneresis weeping out of the product after thermal processing. It is, therefore necessary to control syneresis.

Different types and amounts of water holding substances were studied to reduce the amount of syneresis after sterilization. We observed that after precooking, there was no gelatinous syneresis observed in scrambled eggs containing water holding substances. However, after sterilization, there was undesirable gelatinous syneresis observed in scrambled eggs prepared with carageenan gum and high acyl gellan gum. Even though high acyl gellan gum forms a gel at temperatures between 70 and 80 °C, gelatinous syneresis was observed after subjecting the eggs to variation of temperature from heating (121 °C) to cooling (80 °C). Non-gelling hydrocolloids such as xanthan gum, guar gum were preferred. Different combinations of modified starches and hydrocolloids were tested.

Based on the results obtained from chemical and physical measurements as to a systematic study, we selected the optimum formulation of scrambled eggs for RF sterilization (Table 1). In order to develop a suitable scrambled eggs formulation for RF heating, electrical conductivity was used as a parameter to reflect the averaged power that food obtained under RF heating. The higher the power the less time is needed to achieve high temperature short time (HTST) process.

Table 1. Ingredients of the selected formulation for RF sterilization

Ingredients	**Amount (%)**
Liquid whole eggs	75.08
Water	20.00
Vegetable oil	2.98
Salt	0.59
Citric acid	0.15
Corn starch	1.00
Xanthan gum	0.10
Guar gum	0.10

Judy Gains, representing US Army Natick Soldier Center, visited WSU between December 7-11, 2004 to work with WSU RF team in developing suitable egg formulation for RF heating. Different combinations of ingredients based on Judy's recipe were tested under RF heating. Frozen egg nuggets and new type of liquid egg mixture were supplied by Michael Foods. The RF heated samples from the studies were delivered to Natick for sensory evaluation.

c. Quality evaluation

Elements of quality such as color and texture of RF and retort sterilized scrambled eggs were measured. The comparison of RF and retort heated scrambled eggs showed significant differences in the degree of lightness and redness (Table 2). Retort heating produced darker scrambled eggs. There was no significant difference in texture parameters between the two processes.

Table 2. Color and texture parameters of RF sterilized scrambled eggs

Type of process	L*	a*	b*	Hardness	Springiness	Cohesiveness
Freshly scrambled eggs	85.92±0.08[a]	2.45±0.16[b]	33.79±1.05[a]	N/A[a]	N/A	N/A
RF heated scrambled eggs	83.46±2.78[a]	0.95±0.32[c]	28.10±1.29[b]	928.780 ± 90.590[a]	0.822 ± 0.081[a]	0.451 ± 0.020[a]
Retort heated scrambled eggs	74.12±2.42[b]	6.52±0.72[a]	29.11±1.32[b]	782.400 ± 13.727[a]	0.883 ± 0.047[a]	0.499 ± 0.030[a]

Figure 8. Retorted and RF heated scrambled eggs

d. Improvement of Polymeric Trays

Based on what we observed in the RF heating experiments, we requested Rexam Container to produce some flat-bottom 6-lb capacity polymeric trays so that we could replace our dome-shape bottom trays. The dome-shape bottom trays caused product thickness to be uneven. After six months waiting and a couple of trial at the Rexam Containers, we received several hundred flat-bottom trays in November, 2003. Immediately after receiving the trays, we evaluated RF heating of foods in the new trays and obtained a better heating pattern. The difference in temperature between the four probes was measured within 5° C.

Figure 9. Flat-bottom and dome shape bottom trays

Task 4. Microbial challenge tests

a. Determination of thermal resistance

Clostridium sporogenes is widely used as a surrogate for *C. botulinum*. We received 40 mL of *Clostridium sporogenes* (PA 3679) spores from National Food Processors Association (NFPA) in December, 2003. Thermal resistance (D value) of PA3679 was determined at 121.1 °C in both standard solution (M/15 phosphate buffer) and scrambled eggs.

A selected formulation of scrambled eggs that has been validated to optimize RF heating was used. Scrambled eggs were inoculated with 1.0×10^6 CFU/g of PA3679. Inoculated scrambled eggs of 1 g were filled into novel aluminum TDT tubes before being heated at selected six time intervals. Experiments were conducted in triplicate. D-value of PA3679 in scrambled eggs at 121 °C was 0.75 min. The value was used to validate microbial safety of RF heating system.

b. Inoculated pack studies of RF heating system

Based on the determination of D-values of PA3679 in scrambled eggs, microbial validation of RF heating system was conducted using inoculated pack studies. Scrambled eggs were inoculated with PA3679 spores and packaged in 6-lb capacity polymeric trays. The trays were then processed in the custom-made pilot-scale RF sterilization system with the improved pressurized vessel (Figure 2) at three different sterilization levels: under-target process (F_0~3.0 min), target process (F_0~5.3 min), and over-target process (F_0~9.0 min). The experiments were conducted in triplicate. There was no growth of PA3679 observed from direct plating above the detection limit (150 CFU/tray) in the target and over-target processes. The results of the inoculated pack studies agreed with the calculated lethality of RF heating processes. It indicated that RF heating system can produce safe shelf-stable scrambled eggs.

Dr. Hyun-Jung Chung joined our group in January 2004 to enhance our microbiological capacity. She obtained her Ph. D. degree from the Ohio State University in Food Microbiology after earning her Bachelor's degree in the Department of Food and Nutrition at Sookmyung Women's University in Korea, and a double Master's degree in

Food Science from Seoul National University and Rutgers University. Immediately after joining us, she worked with Kunchalee in conducting microbial challenge tests.

Task 5. Preliminary Economic studies

Our current RF system can only treat one 6-lb capacity polymeric combat ration tray at a time. It is difficult to draw adequate information for a reliable economic analysis, because of the small scale. Economic studies were postponed to Phase 2 which proposes to use a multi-tray RF sterilization system for the economic studies which will be useful for industrial implementation.

Task 6. Produce egg products for Natick

We prepared RF sterilized scrambled eggs for Natick sensory evaluation on December 10, 2003. Microbial counts were examined by Dr. Kang's microbial laboratory at WSU to make sure that the trays were free of pathogenic microorganisms. The sensory results from Natick showed that our products received the highest overall ranking among samples from 5 different organizations processed with different technologies, including ultra high pressure and rapid retorting of small pouches.

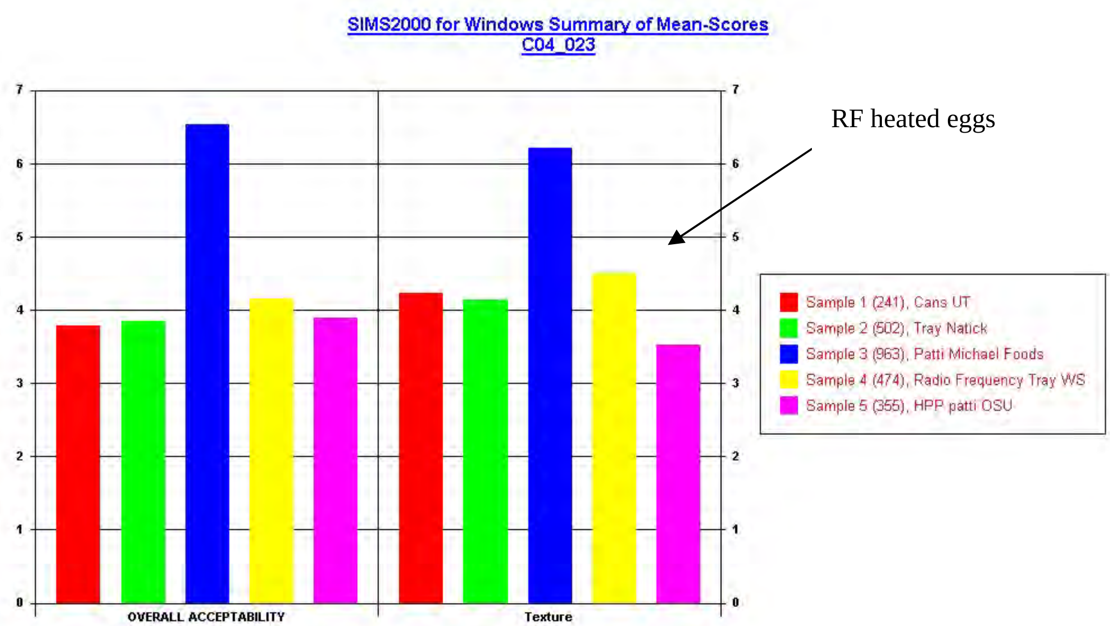


Figure 10. Sensory evaluation results at Natick
Source: Alan Wright

A second batch of samples was sent to the U.S. Army Natick on December 13, 2004. Both technical and consumer sensory evaluations were conducted at Natick on February 14, 2005. Selected RF heated eggs scored greater ($p<0.05$) than retort heated eggs in both appearance and overall quality from technical panels ($n=16$). The results from consumer panels ($n=40$) indicated that RF heated eggs based on WSU's formulation had greater overall acceptability than retort heated eggs ($p<0.05$).

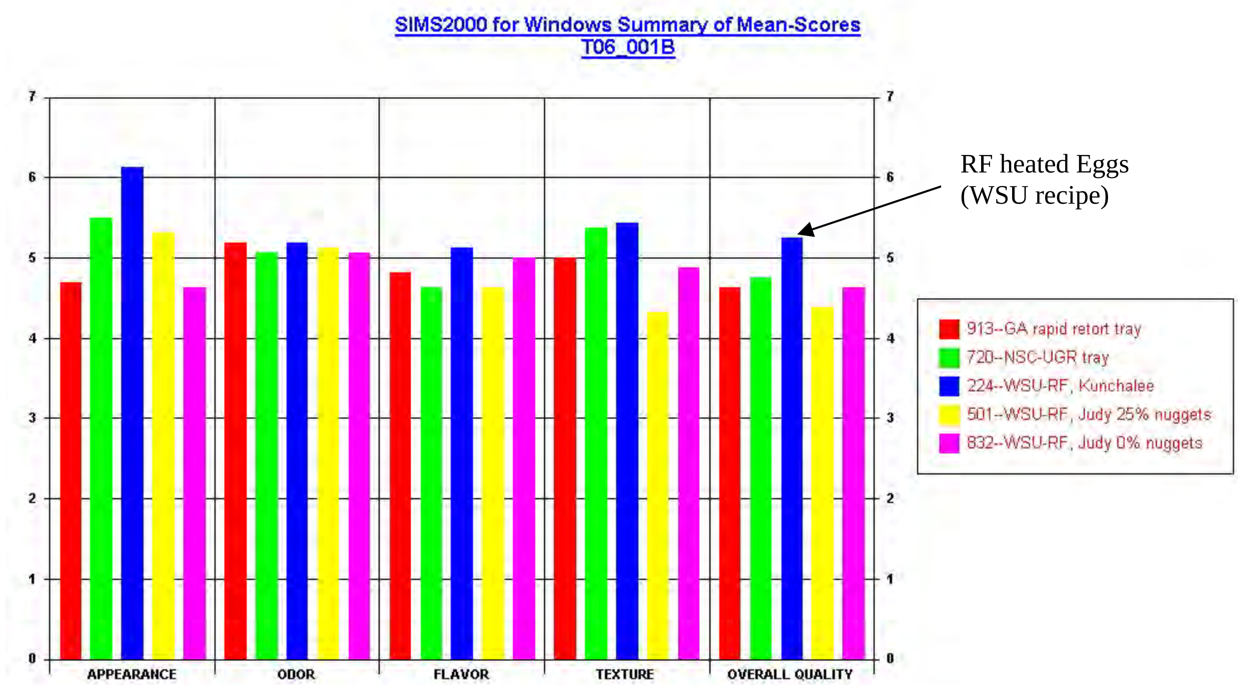


Figure 11. Sensory evaluation results from technical panels at Natick
Source: Judy Gains

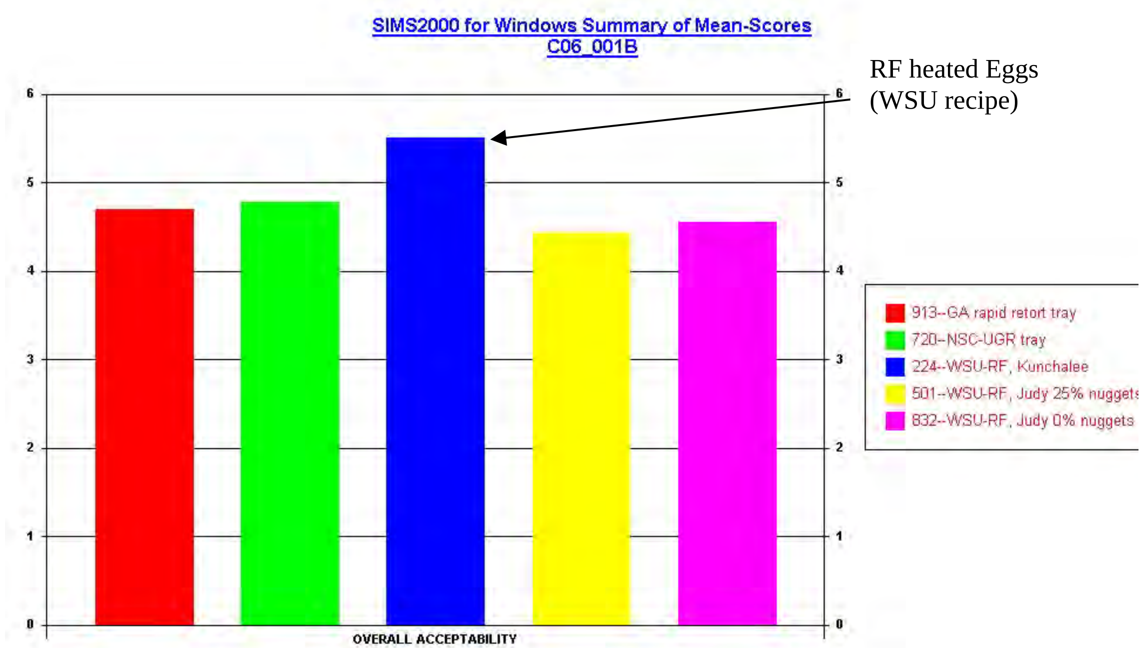


Figure 12. Sensory evaluation results from consumer panels at Natick
Source: Judy Gains

Task 7. Conduct IPR

Dr. Patrick Dunne and Jesse Burns visited WSU and saw a demonstration of RF processing of egg products in 6 lb polymeric trays. A video of preparing and RF processing of egg product was made and played at the CORANET meeting on June 16, 2004 in Cincinnati, OH.

The use of automatic program to control RF heating was initiated during IPR at WSU. We developed the program based on the heating pattern of five manually runs of RF heating. Temperature and over pressure of circulating water was controlled automatically over time. The repeatability of RF heating based on the automatic program was determined. We produced 10 trays of RF heated scrambled eggs without any temperature tubings in the tray. Incubation studies of 6 trays at 37 °C were conducted. There was no gas production observed after incubation for 10 days. Heat distribution inside an RF chamber was studied to gain a better understanding of heat loss during RF heating process and to increase efficiency. It was found that by putting a sheet of plastic underneath the RF vessel could reduce heat loss. Repeatability tests were conducted for the second time. It was found recently that repeatability of current RF heating system is difficult to achieve due to the corrosion of metal electrodes that are fully exposed to water. The corrosion problem will be solved with the second generation of RF heating system.

Task. 8 Develop Final Report

Conclusions in connection with proposed objectives and recommendation for future work
During the first phase of this project, egg formulation that is suitable for RF sterilization was developed. Preliminary research on RF heated egg product resulted in greenish-black discoloration and undesirable syneresis after processing and storage. Extensive studies of effect of each ingredient, packaging materials and cooking method to the quality of final egg product were conducted. The use of additional citric acid and a combination of different water holding substances (corn starch, xanthan gum and guar gum) resulted in neither discoloration nor syneresis observed after RF heating. Dielectric properties of selected formulation were measured to provide a better understanding of how egg product reacts under alternating electromagnetic field. Microbial safety of selected RF heated egg product were ensured by inoculated pack studies using *C. sporogenes* (PA 3679) which has been used as a surrogate of *C. botulinum* in developing processes for sterilized food. Quality evaluation of RF heated egg products comparing to retort heated egg products were conducted using both instrumentation (color, texture) at WSU and sensory evaluation (trained and consumer sensory panels) at Natick. The results indicated that sterilization based on RF energy can produce safe shelf-stable egg products with the potential of producing better quality compared to retort heated egg products. The selected RF heated egg product received greater overall acceptability score ($p<0.05$) comparing to retort heated egg product from both trained and consumer sensory panels.

An improvement of previous RF pressure-proof vessel was conducted to avoid arching and unstable heating as well as shorten loading and unloading time. A mock-up unit was built to study flow of immersion water and development of air pockets in the vessel. There was no arching with the new pressure-proof vessel over the course of one year test. The results of the studies have beneficial to the design of a new RF heating system.

We are building a new RF multi-tray system with 25 kW power supply, we use Teflon lined filament winding tube as a pressurized vessel to contain trays and circulating water. The tube is sandwiched between two metal electrodes. This eliminates the possibility of corrosion and improves the repeatability of RF heating. The new system will be used to further improve the quality of egg products and on the study of engineering and economic feasibility for industrial implementation.

List of Publications Related to the Project

Tang, J, Wang, Y. and Chan, TV, 2005. Radio frequency heating in food processing. In *Novel Food Processing Technologies,* Gustavo Barbosa-Cánovas (Ed.). Marcel Dekker, Inc. p. 501-524.

Luechapattanaporn, K., Wang, Y., Wang, J., Tang, J. Hallberg, L.M. 2004. Microbial safety in radio frequency processing of packaged foods. *J. Food Sci*. 69(7): M201-6.

Luechapattanaporn, K., Wang, Y., Wang, J., Tang, J., Hallberg, L.M, Dunne, C.P. 2005. Sterilization of scrambled eggs in military polymeric trays by radio frequency energy. *J Food Sci*. *70(4):E288-294.*

Chan, T.V., Tang, J., Younce, F. 2004. 3-dimensional numerical modelling of an industrial radio frequency heating system using finite elements. *J. Microwave Powers and Electromagnetic Energy 39(2):87-105.*

Wang, Y., Lau, M.H., Tang, J., and Mao, R. 2004. Kinetics of chemical marker M-1 formation in whey protein gels for developing sterilization processes based on dielectric heating. *J. Food Engineering 64(1):111-118.*

Guan, D., Cheng, M., Wang, Y., Tang, J. 2004. Dielectric properties of mashed potatoes relevant to microwave and radio-frequency pasteurilization and sterilization processes. *J. Food Sci*. *69(1):30-37.*

Wang, Y., Wig, T., Tang, J, and Hallberg, L.M. 2003. Sterilization of foodstuffs using radio frequency heating. *J. Food Sci*. 68(2):*539-544*.

Wang, Y., Wig, T., Tang, J., and Hallberg, L.M. 2003. Dielectric properties of food relevant to RF and microwave pasteurization and sterilization. *J. Food Engineering 57(3):257-268.*

List of Presentations Related to the Project

Luechapattanaporn, K., Wang, Y., Wang, J., Tang, J., Hallberg, L.M. 2005. Dielectric Properties and Radio Frequency Heating of Heterogeneous Foods. ASAE Annual Meeting, July 17-20, Tampa, FL.

Tang, Z., Chan, TV. Tang, J., Younce, F., Al-Shami, A., Luechapattanaporn, K. 2005. Heating Uniformity Study on Packaged Foods Processed by Radio Frequency Energy. ASAE Annual Meeting, July 17-20, Tampa, FL.

Wang J., Tang, Z., Luechapattanaporn, K., Tang, J. 2005. Heating Patterns of Foods during RF Sterilization. IFT Annual Meeting, July 12-16, New Orleans, LA.

Luechapattanaporn, K., Wang, Y., Wang, J., Tang J. 2005. Sterilization of Scrambled Eggs by Radio Frequency Energy. International Conference on Innovations in Food Processing Technology and Engineering, Asian Institute of Technology. January 11-13, Bangkok, Thailand.

Luechapattanaporn, K., Wang, Y., Wang, J., Tang, J. and Hallberg, L. M. 2004. Development of Scrambled Eggs for Army Ration Based on Radio Frequency Sterilization. IFT Annual Meeting, July 12-16, Las Vegas, NV.

Wang, Y., Luechapattanaporn, K., Clark, S., Tang, J. and Hallberg, L. M. 2004. Quality of Egg Products Sterilized by RF Energy. IFT Annual Meeting, July 12-16, Las Vegas, NV.

Wang, J., Wang, Y., Luechapattanaporn, K. And Tang, J. 2004. Dielectric Properties of Eggs in Radio Frequency and Microwave Heating. IFT Annual Meeting, July 12-16, Las Vegas, NV.

List of Participants and Their Roles in the Project

Participants	Role
Yifen Wang	Post-doctoral fellow 2002-July 2004
Zhongwei Tang	Post-doctoral fellow 2004-current
TVCT Chan	Post-doctoral fellow 2004-current
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Jian Wang	Ph. D. Student 2002-current
Ali Al-shami	Ph. D. Student 2003-current
Galina Mikhaylenko	Associate in Research 2002-current
Jessica Jahn	Part-time Student
Jonathan Kijima	Part-time Student